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Improving Splitting Efficiency in Photonic Crystal Waveguide

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Abstract- **Photonic Crystals (PCs) are dielectric structures with periodic spatial alternations of refractive index on the scale of the wavelength of light. Many optical devices, based on PCs, have been proposed. There are multiple ways by which equal amount of power of incoming signals can be divided into two, three and four output channels; for example using multiple coupled photonic crystal waveguides, directional coupling and cascaded multimode PC waveguides. Ideally, the splitter should divide the input power equally into the output channels without significant reflection or radiation losses and should be compact in size. In this paper, optical power splitting using Y-junction has been proposed. The optical modeling of this proposed structure was investigated by finite difference time domain (FDTD) simulation. The goal was to achieve equal power at each output channel with broad spectrum around the target wavelength with low loss.**
Keywords- **Photonic Crystal, Photonic Crystal, Waveguide, Y Junction splitter.**

I. INTRODUCTION

For the past 50 years, semiconductor technology has played a role in almost every aspect of our daily lives. The drive towards miniaturization and high- speed performance of integrated electronic circuits has stimulated considerable research effort around the world. Unfortunately, miniaturization results in circuits with increased resistance and higher levels of power dissipation, and higher speeds lead to a greater sensitivity to signal synchronization. In an effort to further the progress of high-density integration and system performance, scientists are now turning to light instead of electrons as the information carrier.

Light has several advantages over the electron. It can travel in a dielectric material at much greater speeds than an electron in a metallic wire. Light can also carry a larger amount of information per second. The bandwidth of dielectric materials is significantly larger than that of metals: the bandwidth of fibre optic communication systems is typically of the order of one terahertz, while that of electronic systems (such as the telephone) is only a few hundred kilohertz. Furthermore, light particles (or photons) are not as strongly interacting as electrons, which help reduce energy losses. Photonic crystals are the periodic optical nanostructures which affect the motion of photons in a similar manner as the ionic lattices affect electrons in solids. Photonic crystals occur in nature in the form of structural coloration and promise to be useful in different forms in a range of applications.

Photonic crystals can be fabricated in one, two, or three dimensions. One-dimensional photonic crystals is be made of layers deposited or stuck together; two-dimensional ones can be made by drilling holes in a suitable substrate, and three-dimensional ones by, for example, stacking spheres in a matrix and dissolving the spheres [1].

Among the most basic optical components for integrated optics applications are linear waveguides, waveguide bends, and Y splitters [2]. In the past few years, there have been many reports on the design, fabrication, and testing of two- dimensional (2D) photonic crystal guides and bends [3-6]. Quantitative analysis of guiding and bending efficiency at 1.5-1.6 μm wavelengths has also been carried out [4-5]. It is demonstrated that a 2D photonic band gap (PBG) is effective in light guiding and bending in the 2D plane. It is also possible to minimize radiation loss along the third direction by use of a strong-index cladding design [7-9]. The same PBG guiding principle can also be applied to the design of a Y splitter with high efficiency. A PBG splitter can support large angle splitting (>60^0) with low loss and also has a miniature size < 5μm×5μm. However, for a conventional waveguide branch, the Y-splitting angle is restricted by radiation loss to a few (□10) degrees [10-11]. In this paper, we present the design of a 2D PhC waveguide based Y-splitter. To our knowledge, few works have been proposed and analyzed in this field.

II. LITERATURE REVIEW

Since, the implementation of photonic crystal by John and Yablonovitch in 1987 there have been increasing attention paid to develop the nanostructure in micro scale device in various applications [12,13]. PCs have the potential to provide ultra compact photonic component that will enable the miniaturization of optical circuits and promise to revolutionize integrated optics. These photonic components are based on the planar PC structure and operate in the PBG of the periodic dielectric structures which allow control of the light propagation on the wavelength scale. Photonic crystal waveguides (PCWs) are formed by line defects in PC. Thereby light is confined horizontally by an in-plane PBG and vertically by TIR. Because of the PBG effect in a PCW, light can be routed around sharp corners with bending radii of the order of the wavelength. Due to the sharp bend higher-order modes are generated that affect the single mode operation in the PCW [14].

III. DESIGN PROCEDURE

In this section, a two dimensional photonic crystal has been analyzed and designed. After that we have investigated a PCW based Y junction splitter through 2D FDTD simulation method. All the simulations have been performed with the Optiwave OptiFDTD 8.0 software, where 'PWE band solver' is used to calculate photonic band gap and "2D FDTD Simulation" is used to compute the different properties of the Y-splitter. Here, the 2D crystal consists of a rectangular lattice structure of dielectric columns. This structure is designed in the OptiFDTD Layout Designer. The waveguide channel is defined by a material of refractive index 3.35 and the default material used is air with the refractive index of 1. The waveguide width is 1μm and the wafer dimensions are 20μm×20μm. The input wave is taken to be a Gaussian Modulated Continuous Wave having the input wavelength of 1.00385μm.

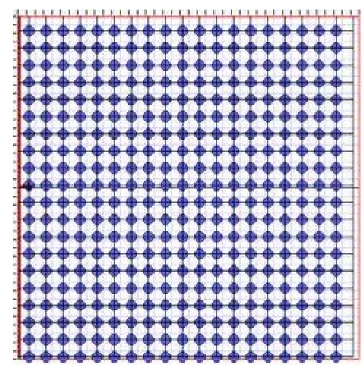

Fig. 1(a) Ph C lattice structure

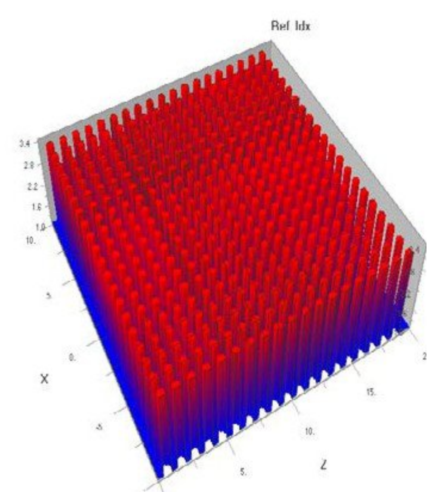

Fig. 1(b) Refractive Index Distribution Profile

The cell radius r and the lattice constant a are defined as r=0.3 and a=0.3. The band gap observed for the above crystal is shown fig.2.

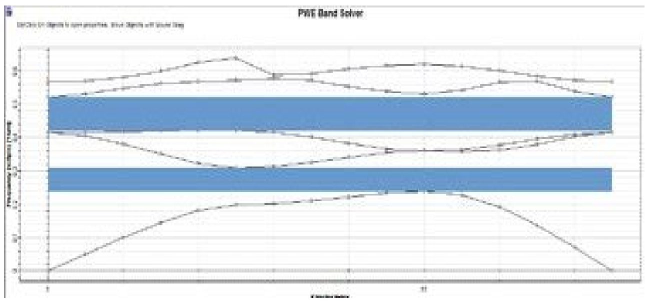

Fig. 2 Band Gap diagram of 2D Ph C

After analysis the desirable communication bandwidth is found at the frequency 1.00385μm.

IV. PHOTONIC CRYSTAL WAVEGUIDE

Waveguides are the important element of photonic integrated circuits (PIC). In this work, it is our core element to design a power Y-splitter. In a PhC, a simple LDW is created by removing a row of dielectric pillars along one of its main crystalline directions as shown in Fig.3 Due to this defect optical signal can be carry between components in the integrated system.

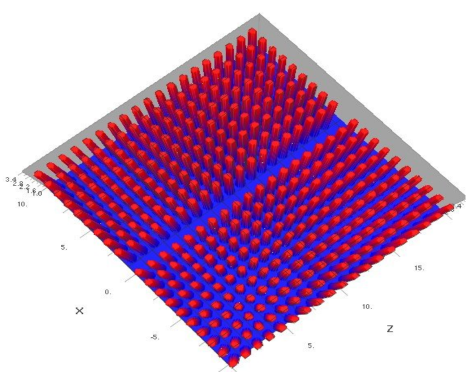

Fig. 3(a) Refractive Index Profile with Line Defect Waveguide

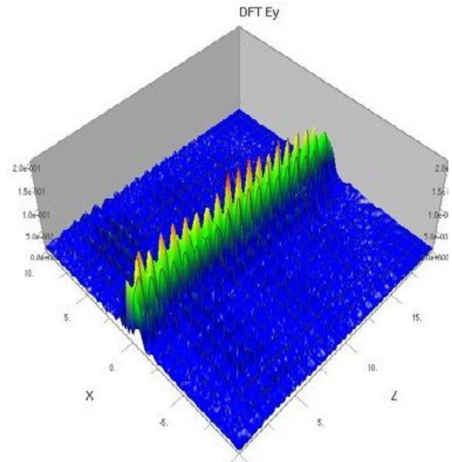

Fig. 3 (b) Electric Field Distribution of Profile

The Electric field distribution is shown in the fig. 3(b) and the electric and magnetic field distribution of the signal is uniform throughout the guiding path and there is minimum attenuation of signal in the structure.

V. 2D Ph C Y SPLITTER

The 2D PhCW based splitter is designed as a Y junction formed by the intersection of three PhCWs at 120^0. To have the output channels of the Y splitter be parallel to the input channel, the two output channels have a 60^0 bend. Both the Y junction and the 60^0 bend represent sever discontinuities in the PhCWs and are potentially regions in which the single- mode operation might suffer from large transmission losses. Therefore, the discontinuities in these regions were carefully designed.

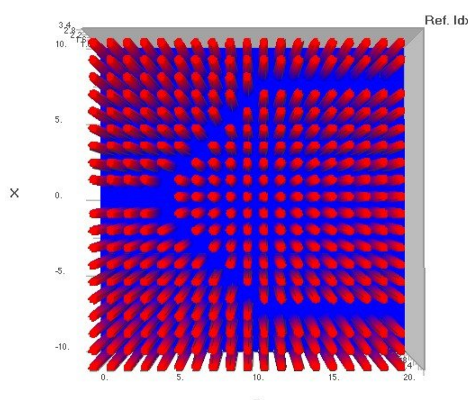

Fig. 4 (a) Refractive Index Profile of Y splitter

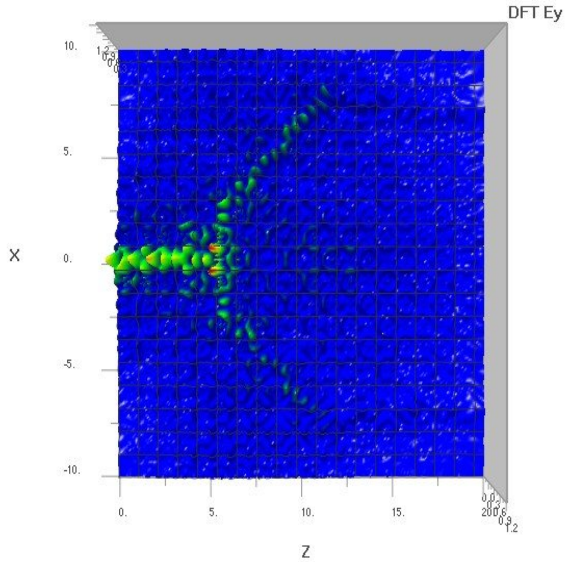

Fig. 4 (b) Electric Field Distribution of Y splitter profile

In summary, our planar PhC Y-junction based structure is defined by an array of dielectric pillars with refractive index of 3.35 in air background, having dimension 20µm×20µm. The regular pillars are placed in a rectangular lattice and have a radius r=0.3, where lattice constant a=0.3. The PC Y- junction base structure is formed by the intersection of three PCWs at 120^0. The output channels of Y splitter are parallel to the input channel and have a 60^0 bend and seven periods spaced from the Y junction.

VI. MODIFICATION IN DESIGN

The crystal is designed in an elliptical shape by changing the values of cell radius to as major radius =0.3 and minor radius =0.1. So the layout becomes an elliptical Y shape 2D photonic crystal. The crystal design and refractive index are shown in fig. 5(a) & (b) respectively.

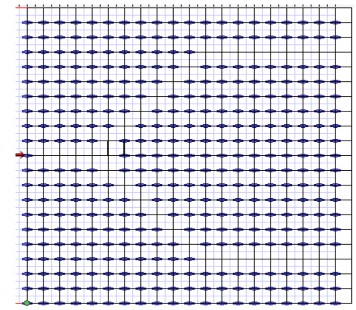

Fig. 5 (a) Crystal lattice layout of elliptical Y splitter

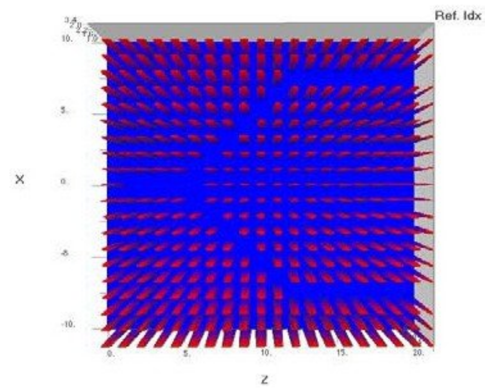

Fig. 5 (b) Refractive Index Profile for the elliptical Y splitter

The band gap for the above design is shown below

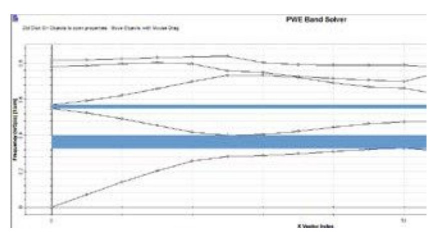

Fig. 6 Band Gap Diagram for elliptical Y shape splitter crystal

VII. RESULT AND ANALYSIS

As the mode analysis and band gap analysis is done for three designs, the band gap characteristics are improved for the 2D photonic crystal fiber than the 2D elliptical Y splitter photonic crystal. Since, the band gap analysis is completed for photonic splitting device applications two band gaps have been found at the end. A comparison is shown in the table I for all designs.

Table I
Band Gap Comparison for Designed Photonic Structures

S.No.	Structure	Band Gaps	Range of band gap	Tolerance
1	2D Y splitter photonic crystal	2	0.23823-0.308293 0.421687-0.521303	0.01
2	2D elliptical Y splitter photonic crystal	2	0.326432-0.398787 0.548518-0.568208	0.01

VIII. CONCLUSION

Y-junction based 1×2 power splitter formed in 2-D PC is analyzed primarily by using 2-D FDTD computational method. 120^0 junction and 60^0 bend are optimized for obtaining maximum power transmission in 1×2 Y-junction based power splitter. Also we have formed a Y junction based 1×2 elliptical power splitter in 2D PC. The computation is done in the same 2D FDTD computational method.

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